# Design, Optimization, and Control of a 100-kW Electric Traction Motor Meeting or Exceeding DOE 2025 Targets

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Project ID: ELT250
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## OVERVIEW

### Timeline

- Project start date: April 2019
- Project end date: March 2024
- Percent complete: ~60%

### Budget

- Total project funding: $1,700,000
- U.S. Department of Energy (DOE) share: $1,500,000
- Funding for FY 2021: $300,000

### Barriers addressed

- Power density, cost, and lifetime.

## RELEVANCE

This project is part of the Electric Drive Technologies (EDT) Consortium and focuses on IIT's role under Keystone 2. The research enables power dense and low cost electric machines

- Despite intensive research efforts the cost of electric traction motors has not fallen sufficiently
- The price of fundamental materials (i.e. steel, copper, etc.) is unlikely to substantially decrease
- Holistic approach is needed considering design, materials, winding technology, cooling, and controls

## COLLABORATIONS

- Electric Drive Technologies Consortium Motor Team Members: ORNL, NREL, SNL, AMES, UW-Madison, Purdue, NCSU

## ACKNOWLEDGMENTS

Susan Rogers, U.S. Department of Energy

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## APPROACH

### Electric Motor Optimization

- Create new multiphysics optimization tools and techniques to increase the power density and efficiency of traction electric motors
- Magneto-structural combined dimensional and topology optimization for rotor design
- Metamodel based optimization for drive cycle efficiency

### High Slot Fill Windings

- Develop new winding technologies with high slot fill to reduce ohmic losses and enhance heat transfer of losses
- Cast or additively manufactured copper coils
- Die compressed coils using round magnet wire
- Rectangular conductor winding manufacturing

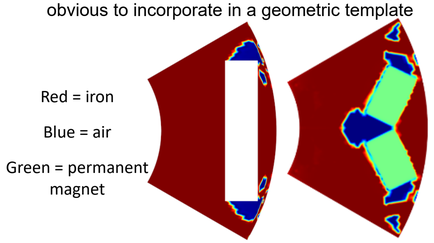
### Prototype Electric Motors

- Design reduced power density and 100 kW electric traction motors to demonstrate developed technology
- Incremental develop process with one prototype designed per budget period and prototyped the following budget period

## ACCOMPLISHMENTS AND PROGRESS

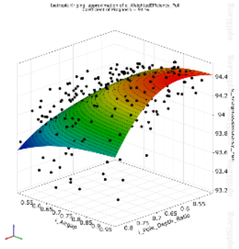
### Electric Motor Optimization

- Additional work on two techniques for magneto-structural combined dimensional and topology optimization that have been developed during the course of this project
  - Dimensions of block magnet can vary while surrounding iron/air is topology optimized
  - Small features in iron are created which might not be obvious to incorporate in a geometric template

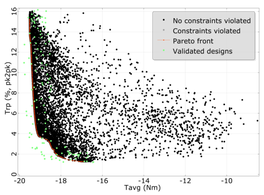



Mesh deformation PM function projection

- Improved and extended magneto-structural metamodeling based optimization for drive cycle optimization
  - Maximize efficiency over a drive cycle subject to constraints



Representative metamodel surface for weighted efficiency

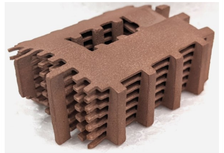



Metamodel can be used to construct a Pareto front of potential designs

### High Slot Fill Windings

- Cast and binder jet printed concentrated trial coils have been prototyped

Cast concentrated copper coil

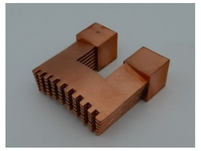


Binder jet printed copper coil

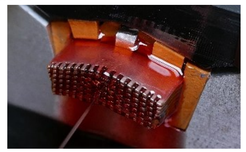
- A polyimide coating process has been developed to coat the cast or additively manufactured coils

Representative polyimide coated test coupon

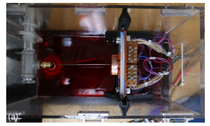
- Cast and additively manufactured coils can incorporate enhanced heat transfer features and surfaces (Provisional patent filed)
- For example, half coils with end turn spray cooling heat transfer enhancement surfaces



Half coil with increased end turn surface area



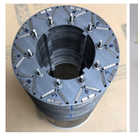
Spray onto end turn surface



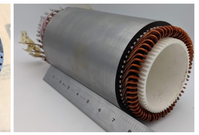
Flexible spray cooling test setup

### Prototype Construction

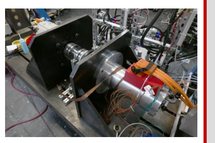
- An interior permanent synchronous machine (IPMSM) prototype designed in budget period 2 using a metamodel drive cycle based approach was prototyped this budget period
- The prototype is designed for a peak power output of 100 kW and has a stator core volume of 2 liters (50 kW/l active power density) with a 6,600 RPM base speed
- Preliminary dynamometer testing completed and matches FEA predictions relatively well



IPMSM Rotor

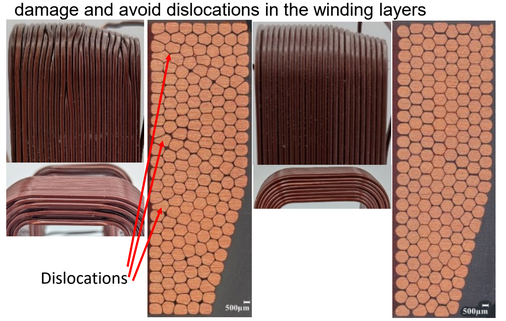


Lap wound stator



Prototype mounted on dynamometer

- A new winding pattern and technique for die compressed windings has been developed to minimize the insulation damage and avoid dislocations in the winding layers




Standard orthocyclic winding pattern after compression

New winding pattern after compression

- Provisional patent filed for this new winding pattern

## FUTURE WORK

- Continued development of combined dimensional and topology optimization techniques
- Further develop binder jet printed copper coil process
- Heat transfer measurements of spray cooling of cast/additively manufactured coils with end turn surface enhancements
- Further improvements to coil die compression and design of a machine using the technology
- Full dynamometer testing of recently constructed motor prototype
- Fabrication of next generation prototype electric machine designed in this budget period

*Any proposed future work is subject to change based on funding levels.*

## SUMMARY

### Approach/Strategy

- This research is directly applicable to the design, optimization, and performance of high power density and low cost electric traction motors aligned with roadmap research areas
- Ultimately the power density of an electric machine depends on the current loading, airgap flux density, and rotational speed
  - This research is trying to improve the current loading capability by researching high slot fill windings
  - Combined dimensional and topology optimization can find rotor structures which maximize the airgap flux density while staying within structural constraints
  - Prototypes are regularly constructed in each budget period to validate the research

### Technical Accomplishments

- Development of magneto-structural combined dimensional and topology optimization
- Development of cast or additively manufactured copper coils with enhanced heat transfer features
- New winding technique for die compressed coils which minimizes insulation damage
- Construction completion of motor prototype designed in budget period 2